Thermal Analysis of ECU Controller

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Abstract - *Engine Control Unit is one of the major component of any vehicle and is frequently used, in commercial vehicles. With many functions being controlled by ECU and considerable optimization in size of it, many integrated circuits are put together. Their continuous work for long time results in their increased temperature. Thermal analysis determines the temperature distribution and corresponding heat flux at various parts of the ECU. The present work attempts to maintain the base temperature at 80⁰ C at minimum increased weight from fins. Finite Element Analysis is carried out to determine the behavior of fins. The CAE results determined using HyperMesh and OptiStruct are compared for validation.*

Keywords- *Engine Control Unit, CAE, HyperMesh, Finite Element Analysis, Thermal analysis, OptiStruct*

1. INTRODUCTION

An engine control unit (ECU), also commonly called an engine control module (ECM), is a type of electronic control unit that controls a series of actuators on an internal combustion engine to ensure optimal engine performance [5]. For long working hours, they get significantly heated up. Overheating causes certain problems to it. It increases the resistance to current flow inside it and also causes a risk of failure to delicate components. Hence the project is based on determining the design for optimum heat dissipation so as to set the temperature under acceptable limits. The increment in surface area is a common method to boost heat dissipation. The fins are added for the same purpose. After achieving the desired temperature, several iterations are done to achieve the same result with minimum added mass of fins.

1.1 Working Principle

The aim is to dissipate the heat from the ECU controller. At the beginning, when there are no fins, heat dissipation to surroundings from casing takes place through convection. As we know that,

$$Q = h\,A\,(t_{sur} - t_{surr}) \qquad .....(i)$$

Where,

Q = Rate of heat dissipation (W)

h = Convective heat transfer coefficient (W/m²/⁰C)

t_{sur} = Surface temperature of casing

t_{surr} = Surrounding temperature

Here value of Q will be fixed. The heat is generated due to the flow of current in the motherboard. As voltage and current flowing is constant, a part of power (product of voltage and current) is released as heat. The heat through the fixtures comes to casing from where it is dissipated to surroundings.

As in eqn. (i), value of Q is fixed, value of h depends property of material and surrounding conditions, and t_{surr} being taken constant, surface area (A) and surface temperature (t_{sur}) are inversely proportional to each other. Since our target is to bring down surface temperature, extending the surface area is the option for which fins are used. Fins are placed based on construction viability and the specific areas where temperature is higher. Although there are various types of fins, the test fins used here are fins of rectangular cross-section in a series of iterations.

The convective heat transfer coefficient h is calculated as follows-

The surrounding fluid is taken as air at 30⁰ C. Taking thermal properties of air at this temperature,

Prandtl Number, $Pr = 0.712$

Now, $\beta = \frac{1}{T}$

$\beta = 0.0033\ K^{-1}$

Now,

Grashoff Number, $Gr = \frac{g\beta\rho^2\,(Tw - Tf)\,Lc^3}{\mu^2}$

$Gr = 2.05 \times 10^8$

So, $GrPr = 1.45 \times 10^8$

Since, $10^4 < GrPr < 10^9$, so this is a case of laminar flow.

Nusselt Number, $Nu = C\,(GrPr)^n$

$= 0.54\,(1.45 \times 10^8)^{0.25}$

$= 59.35$

We also know that,

$Nu = \frac{hL}{k}$

Taking $k = 26.38 \times 10^{-3}$ W/m/K and $L = 0.245$ m, we get

$h = 6.39$ W/m²/K

(*Note: The value of 'h' is calculated assuming horizontal plate conditions* [1]*)*.

Now, $Q= h A (t_{sur} - t_{surr})$

$= 152.75$ W

Heat flux= Q/A = 0.000607 W/mm^2

The heat transfer through fins is given by-

$$Q_{fin} = \sqrt{hpkA}_0 (t_0 - t_a) \left\{\frac{\tanh(ml) + h/km}{1+\frac{h}{km}\tanh(ml)}\right\}$$

Where, $m = \sqrt{hp} / kA_{cs}$ [2]

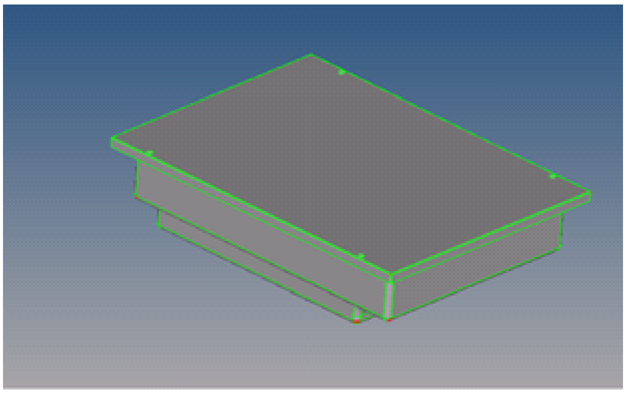

Figure- 1: CAD Model of ECU

2. ANALYSIS

The analysis is performed firstly on model without fins followed by five iterations with fins. In the ECU, casing is the outermost part. Hence, the heat generated is applied here in the form of heat flux and then subsequent analysis is carried out.

2.1 General Specifications

2.1.1 Material

The material used here is Aluminium due to its light weight and good thermal conductivity.

2.1.2 Details of Pre-Processing

Table- 1: Details of Pre-Processing

Parameters	Details
Pre- Processor	HyperMesh
Solver	OptiStruct
Post-Processor	HyperView
Element Size	5

2.1.3 Boundary Conditions

Ambient temperature= 30^0 C
Heat flux= 0.000607 W/mm^2
The boundary conditions will be same in each iteration.

2.2 Model without Fins

2.2.1 Dimensions

Table- 2: Dimensions of Model without Fins

Maximum Length	339 mm
Maximum Width	245 mm
Height	95 mm

2.2.2 Analysis

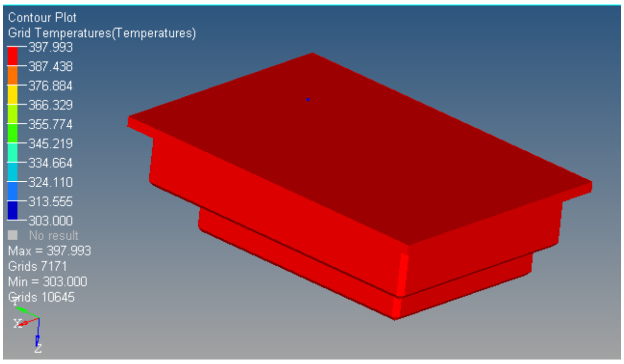

Figure- 2: Temperature Profile

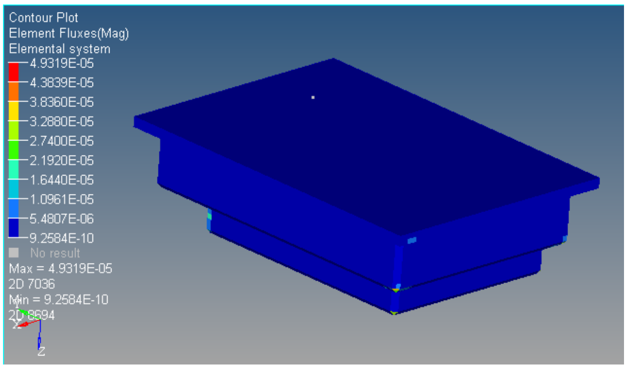

Figure- 3: Heat Flux Profile

2.2.3 Observations

- Since the heat flux profile is uniform, the temperature distribution is also uniform.
- The maximum temperature observed on surface is 125^0 C.

Table- 3: Results of model without fins

Parameters	Details
Maximum Temperature	125^0 C
Base Mass	1359 Grams
Added Mass	0 Gram
Total Mass	1359 Grams

2.3 Iteration I

Since in previous case, the temperature recorded is 125^0 C, it has to be brought down to 80^0 C. In the first iteration, fins of rectangular cross-section are used over the top surface as per constructive feasibility. The material used for fins is Aluminium.

2.3 Iteration I

Since in previous case, the temperature recorded is 125^0 C, it has to be brought down to 80^0 C. In the first iteration, fins of rectangular cross-section are used over the top surface as per constructive feasibility. The material used for fins is Aluminium.

2.3.1 Meshed Model

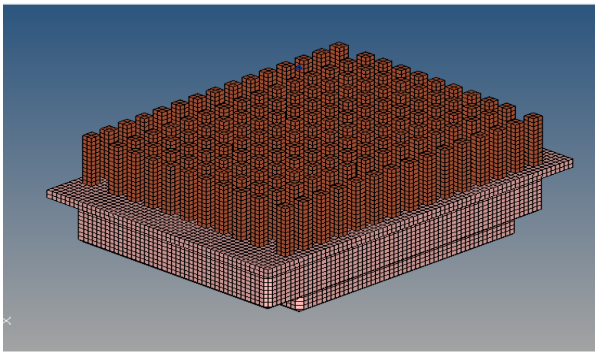

Figure- 4: Meshed Model (i)

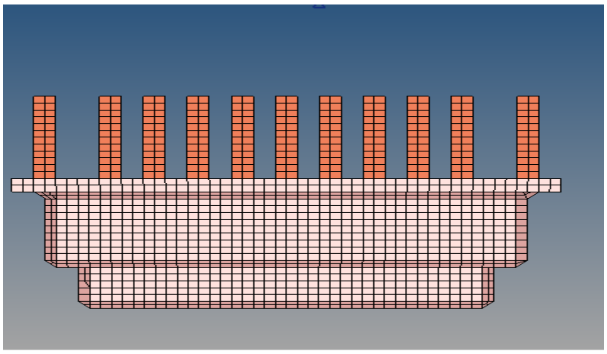

Figure- 5: Meshed Model (ii)

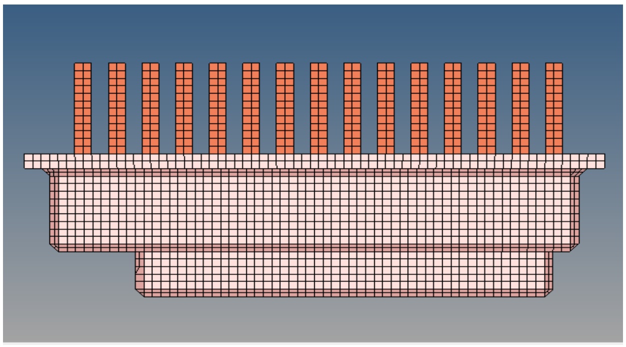

Figure- 6: Meshed Model (iii)

The type of meshing used is Quad-mesh for casing and Hexa-mesh for fins.

2.3.2 Analysis Results

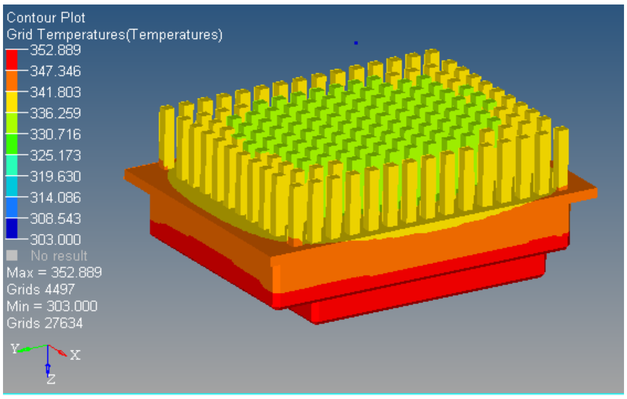

Figure- 7: Temperature Profile

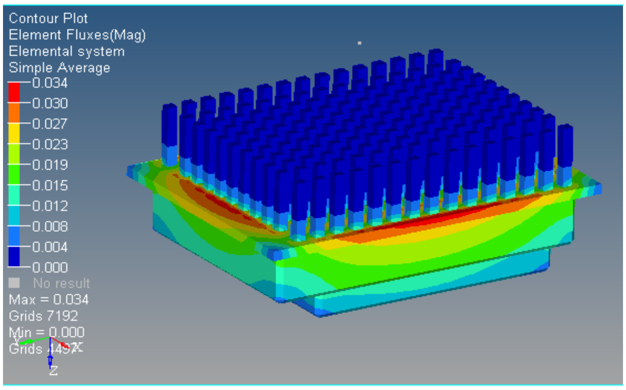

Figure- 8: Heat Flux Profile

2.3.3 Observations

- With the placement of fins, the temperature varies significantly.
- The maximum temperature observed on surface is 79.9^0 C which is well under the limits.
- The added mass due to fins is 2574 grams.

Table- 4: Results of iteration I

Parameters	Details
Maximum Temperature	79.9^0 C
Base Mass	1359 Grams
Added Mass	2574 Grams
Total Mass	3933 Grams

2.4 Iteration II

In the previous case, the maximum temperature was achieved under 80^0 C. But due to placement of fins there was a significant increment in mass. With the previous results, we now determine those fins which had lesser role in releasing heat and removing them. Instead extending the surface on the bottom part where surface temperature were recorded high, would balance the effect of eliminated fins. This forms the basis of iteration II.

2.4.1 Meshed Model

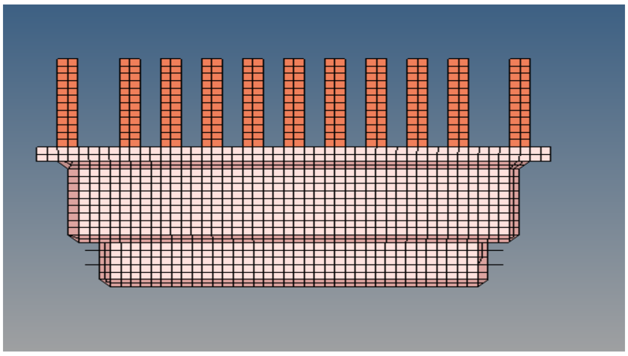

Figure- 9: Meshed Model (i)

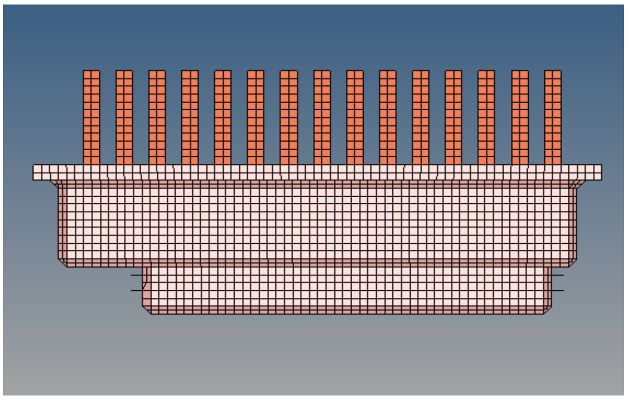

Figure- 10: Meshed Model (ii)

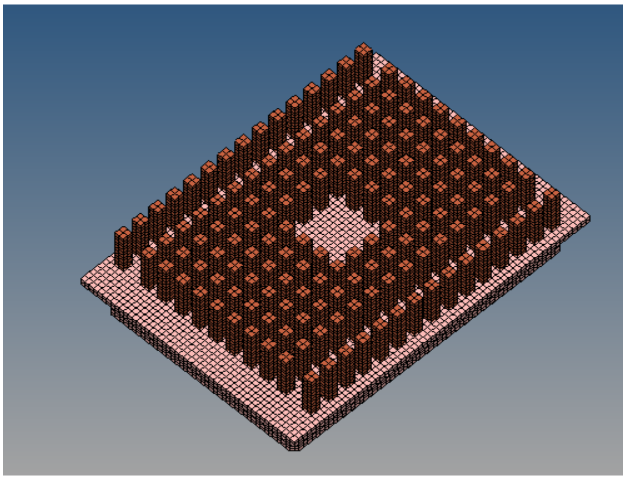

Figure- 11: Meshed Model (iii)

The type of meshing used is Quad-mesh for casing and Hexa-mesh for fins.

2.4.2 Analysis Results

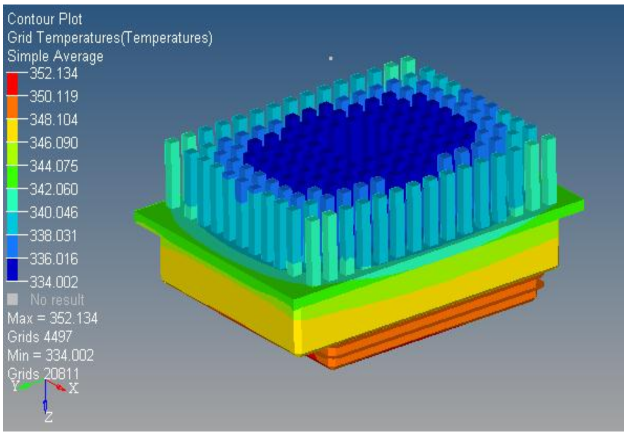

Figure- 12: Temperature Profile

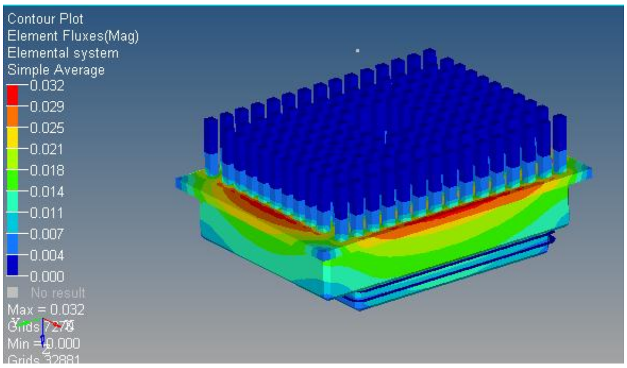

Figure- 13: Heat Flux Profile

2.4.3 Observations

- The maximum temperature observed on surface is 79.1^0 C which is well under the limits.
- The added mass due to fins is 2499 grams.
- There is certain mass optimization due to better positioning of fins.

Table- 5: Results of iteration II

Parameters	Details
Maximum Temperature	79.1^0 C
Base Mass	1359 Grams
Added Mass	2499 Grams
Total Mass	3858 Grams

2.5 Iteration III

As in iteration II, the mass gets reduced with same end results, this iteration also follows the same process with placement of fins at the bottom and reducing the height of fins as the heat dissipation at the end of fins is low.

2.5.1 Meshed Model

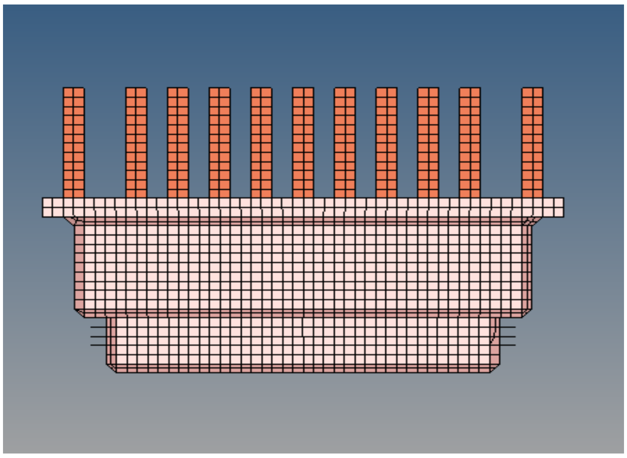

Figure- 14: Meshed Model (i)

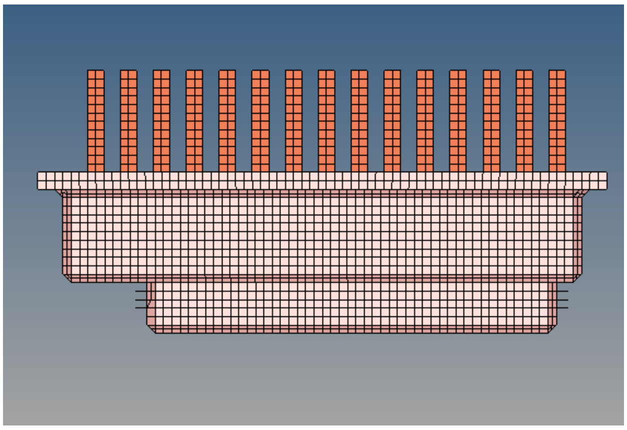

Figure- 15: Meshed Model (ii)

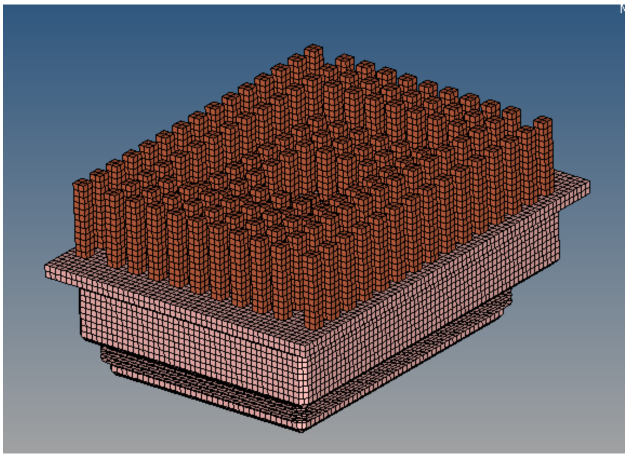

Figure- 16: Meshed Model (iii)

The type of meshing used is Quad-mesh for casing and Hexa-mesh for fins.

2.5.2 Analysis Results

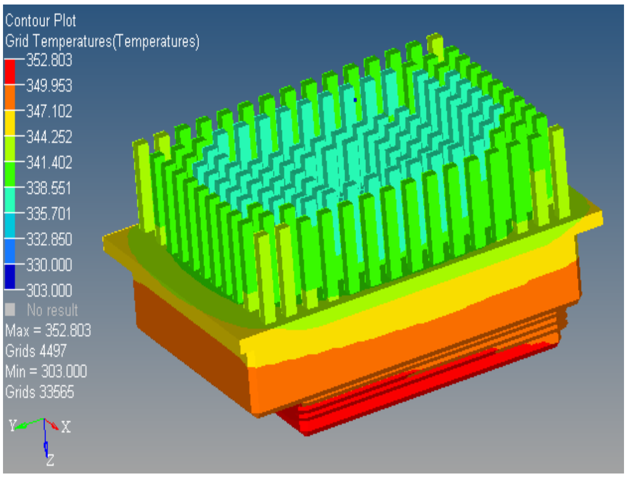

Figure- 17: Temperature Profile

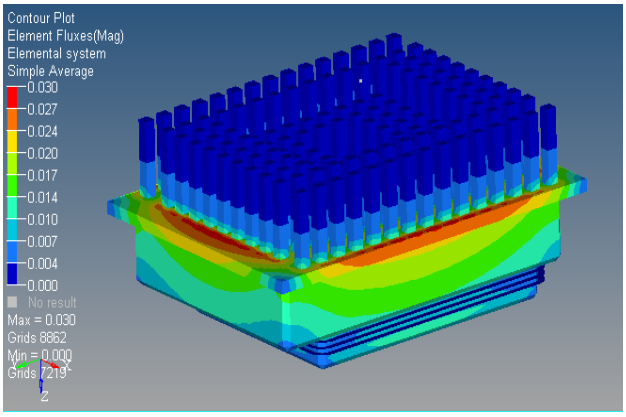

Figure- 18: Heat Flux Profile

2.5.3 Observations

- The maximum temperature observed on surface is 79.8^0 C which is well under the limits.
- The added mass due to fins is 2274 grams.
- Reducing length of fins for extending surface at lower portion reduces mass significantly for the same results.

Table- 6: Results of iteration III

Parameters	Details
Maximum Temperature	79.8^0 C
Base Mass	1359 Grams
Added Mass	2274 Grams
Total Mass	3633 Grams

2.6 Iteration IV

As we know that with increase in surface area, heat transfer rate increases. Now, for the same fins, if they are divided along their length, it would result in generation of new surfaces exposed to surroundings. This forms the basis of iteration IV.

2.6.1 Meshed Model

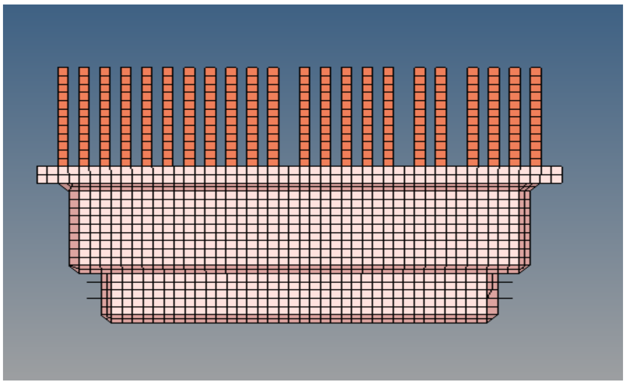

Figure- 19: Meshed Model (i)

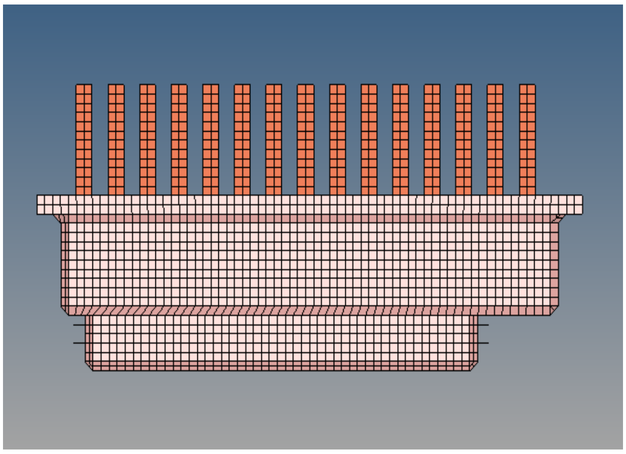

Figure- 20: Meshed Model (ii)

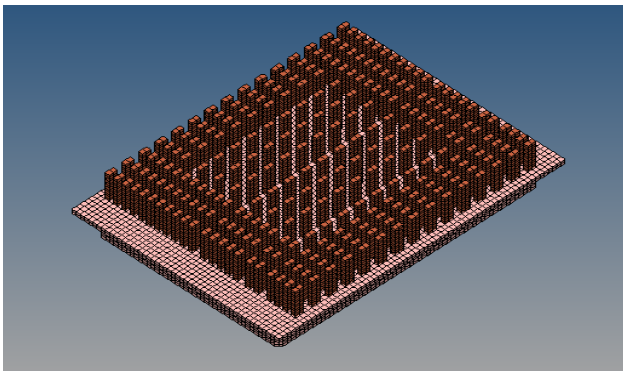

Figure- 21: Meshed Model (iii)

The type of meshing used is Quad-mesh for casing and Hexa-mesh for fins.

2.6.2 Analysis Results

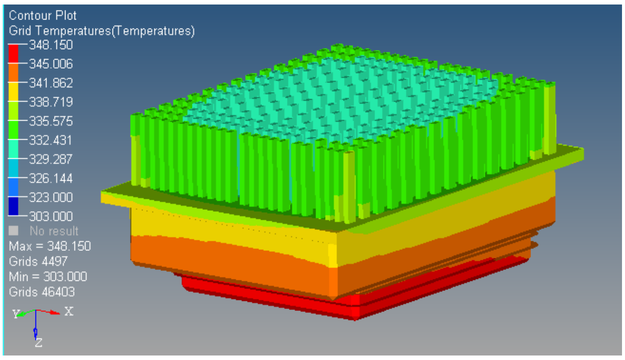

Figure- 22: Temperature Profile

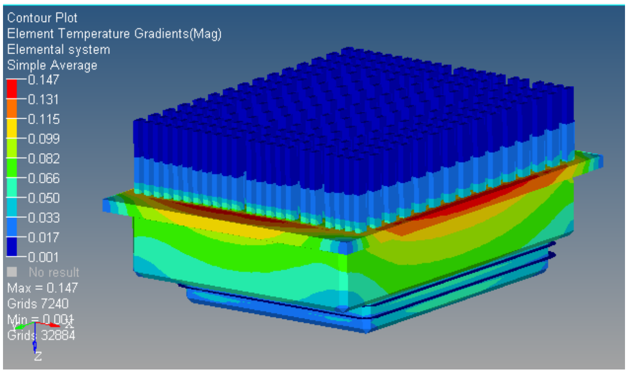

Figure- 23: Heat Flux Profile

2.6.3 Observations

- The maximum temperature observed on surface is 75.15^0 C which is well under the limits.
- The added mass due to fins is 2148 grams.
- Since the temperature becomes low compared to limit, it paves the way for major mass reduction.

Table- 7: Results of iteration IV

Parameters	Details
Maximum Temperature	75.15^0 C
Base Mass	1359 Grams
Added Mass	2148 Grams
Total Mass	3507 Grams

2.7 Iteration V

As in previous case, the temperature was very low so mass can be reduced greatly without any new addition. Since the tips of fins have least significance in heat dissipation, reducing the height of fins is the best option. This forms the basis of iteration V.

2.7.1 Meshed Model

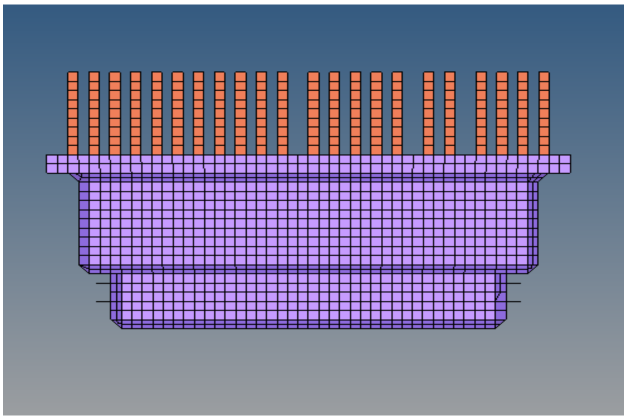

Figure- 24: Meshed Model (i)

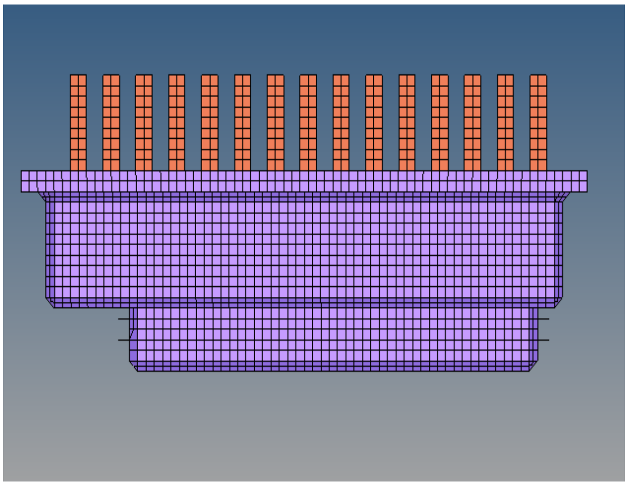

Figure- 25: Meshed Model (ii)

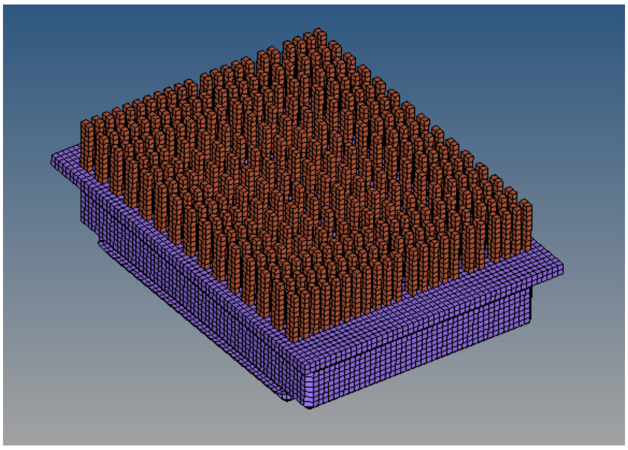

Figure- 26: Meshed Model (iii)

The type of meshing used is Quad-mesh for casing and Hexa-mesh for fins.

2.7.2 Analysis Results

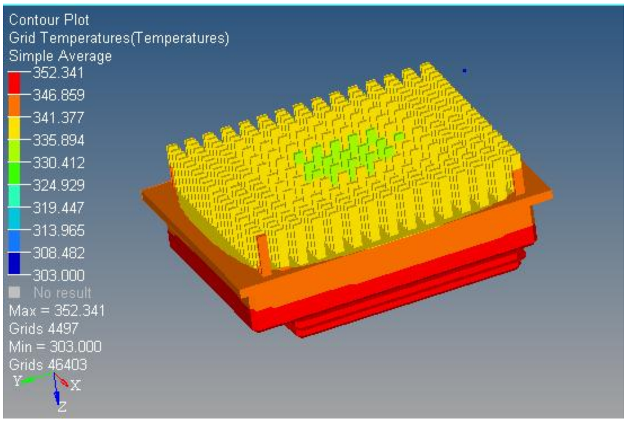

Figure- 27: Temperature Profile

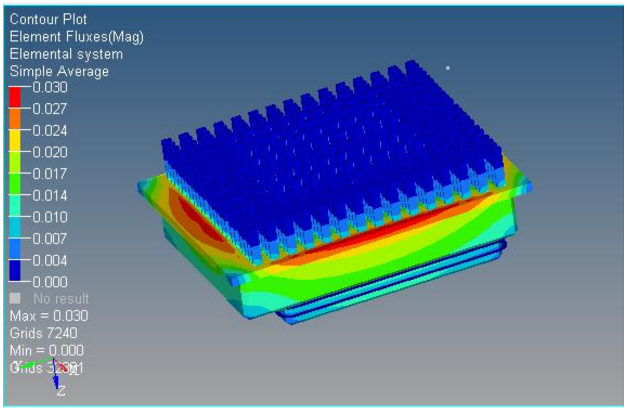

Figure- 28: Heat Flux Profile

2.7.3 Observations

Table- 8: Results of iteration V

Parameters	Details
Maximum Temperature	79.3^0 C
Base Mass	1359 Grams
Added Mass	1627 Grams
Total Mass	2986 Grams

2.8 Comparison of Results

Table- 9: Comparison of all results

	Max. Temperature (^{0}C)	Base Mass (grams)	Added Mass (grams)	Total Mass (grams)
Without fin	125	1359	0	1359
Iteration 1	79.9	1359	2574	3933
Iteration 2	79.1	1359	2499	3858

Iteration 3	79.8	1359	2274	3633
Iteration 4	75.15	1359	2148	3507
Iteration 5	79.3	1359	1627	2986

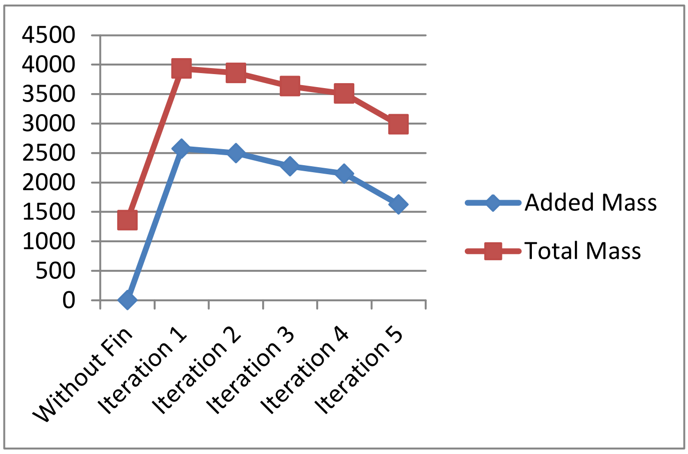

Chart-1: Graphical representation of comparison of masses

3. CONCLUSION

The project is aimed at keeping the component thermally safe with minimum addition in mass. Heat rejection is a vital requirement in electronic items. So for ECU to work effectively, proper heat dissipation is required. Heat dissipation is generally achieved by extending the surface areas. Extending the surface area adds mass which affects the overall efficiency. In this project, the temperature of casing is brought down to 80^{0}C to keep ECU safe with the addition of fins. Five simultaneous iterations are done to maintain the same temperature with additional mass reducing in each following case. The additional mass at the end of fifth iteration is 1627 grams down from 2574 grams at first iteration. The iterations can be continued further also with the same objective.

4. FUTURE SCOPE

In this project, five iterations were done in the direction of weight optimization with end results of analysis remaining intact. This can be continued further using several other means of weight optimization. Some of the ways are-

- Further dividing the fins along their length to get more surface area in contact with surroundings and reducing their overall length.
- Extending surface area along various layers at lower portion of casing where temperature is high and reducing number or height of fins.

Not only just static conditions, thermal analysis can also be done using forced convection from air at certain speed. This can be achieved by using a small fan. This will further reduce the additional mass used in ECU as fins.

5. ACKNOWLEDGEMENTS

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